Wavelength and Power Stabilization of a three wavelength Erbium doped fiber laser using a Nonlinear Optical Loop Mirror

Qhumayo S.[a], Rodolfo Martínez Manuel[a,b] and Grobler M.[a]
[a]Electrical and Electronic Engineering Science Department, University of Johannesburg, Auckland Park 2006, Republic of South Africa;
[b]Centro de Investigaciones en Óptica, A.C. Photonics, Prol. Constitución 607, Fracc. Reserva Loma Bonita Aguascalientes, 20200, México.
Email: siyaz.qhumayo@gmail.com

***Abstract*—This paper describes the use of a Nonlinear Loop Mirror to achieve wavelength and power stabilization in a three wavelength Erbium doped fiber ring laser. The laser uses three fiber Bragg grating reflectors as the oscillation wavelength selecting filters. The influence of the length of the Nonlinear Loop Mirror (NOLM) on the laser stability both in terms of wavelength and laser output power was investigated. The laser performance was improved by changing the length of the Loop Mirror to an optimal length and three simultaneous wavelength oscillations with acceptable power and wavelength stability were achieved.**

***Index Terms*—Three wavelength, Erbium doped fiber Laser, Nonlinear optical loop mirror.**

I. Introduction

Multi-wavelength Erbium doped fiber lasers in the last two decades have attracted a great deal of research interest because of their applicability to telecommunications, fiber sensors and spectroscopy. For telecommunications, in particular, Erbium doped fiber lasers exhibit excellent characteristics that include their ability to emit simultaneous wavelength oscillations making them multi-wavelength optical sources that could be applied in wavelength division multiplexing systems. In addition, these fiber lasers have emissions in the optical fiber low loss wavelength region, commonly known as Telecommunications C-band, over which Erbium doped fiber Amplifiers (EDFA) operate.

The well known pitfall of Multi-wavelength Erbium doped fiber lasers (MW-EDFL) is that, at room temperature, EDFL cavity tends to oscillate at one wavelength at any particular time. This is caused by the wavelength competition that arises from the cross-gain saturation, existing as a result of the predominantly homogeneously broadened Erbium Doped Fiber (EDF) gain at room temperature, leading to unstable oscillations [1][2]. Much of the previous and current research in this area has focused on developing techniques to overcome this challenge. As such, several techniques to mitigate the effect of cross-gain saturation have been proposed and implemented with varying degrees of success. For example, it has been observed that the homogeneous linewidth of EDF exceeds 10nm at 290K and decreases with temperature, down to 1nm at 77K [2]. Hence, cooling the EDF in liquid nitrogen at 77K to reduce the homogeneous linewidth and inserting the intracavity Fabry-Perot etalon as oscillation wavelength filter have been used [2]. Exploiting the intracavity polarization evolution for emission wavelengths, a similar cooling mechanism proved effective [3]. However, this technique is suitable for a laboratory environment and inconvenient for field applications due to its bulkiness. Simultaneous lasing was achieved by using the inhomogeneous gain medium provided by a twin-core Erbium doped fiber [4]. Complexity is still an issue in this design. Some of the required characteristics of MW-EDFL are that they should meet the International Telecommunication union standard ITU-T which specifies that the frequency spacing between adjacent channels should be 1.6 nm, 0.8nm, 0.4 nm or 0.2nm [5][6]; and that the power distribution between channels be uniform. From a design perspective, that emphasizes the importance of having control over the wavelengths that oscillate in a laser system. Using separate gain media for each oscillation wavelength guarantees simultaneous wavelength oscillation at any given time [7]. However meeting ITU-T standards using this configuration will be a challenge. Incorporating a Raman amplifier or semiconductor optical amplifier in the laser cavity can also mitigate the effect of the homogeneous broadening in MW-EDFL [8][9][10], however, this is not a pure Erbium doped fiber laser system, but a hybrid of gain media. That might need additional design consideration since the gain media behavior is different.

An intensity dependent loss mechanism introduced by a nonlinear loop mirror is by far proving to be the simplest method of mitigating the cross-gain saturation in multi-wavelength Erbium doped fiber lasers [11][12][13][14]. In all the above reported work, the focus has been on multiwavelength generation on an Erbium doped fiber gain medium, with little or no intention to gain control on the wavelengths oscillation in the laser cavity. In this work, we exploit the intracavity intensity dependent loss ability of the Nonlinear Loop Mirror to stabilize the power and oscillation wavelength of the fiber laser with complete control over laser oscillation wavelengths. The wavelength control was achieved by Fiber Bragg gratings (FBG) as the wavelength selecting filters. Thus, the wavelength spacing, the number of wavelengths and the exact center wavelength oscillation can be controlled using our configuration. The ability to control the above laser parameters is important for the ITU-T standardization of laser sources for wavelength division multiplexing systems [6]. Experimental characterization has been performed, and a three wavelength laser with oscillations at 1540nm, 1547nm and 1555nm have been achieved. This comes after adjusting the length of the NOLM to an optimal value convenient for stability in the configuration.

II. EXPERIMENTAL SETUP AND PRINCIPLE OF OPERATION

A schematic of the experimental setup is shown on figure 1. A laser diode (LD) pump of 980nm wavelength and 80 mW of pump power is used. This pump power is coupled to a 2.5 m Erbium doped fiber gain medium by a wavelength division multiplexer (WDM) coupler. A nonlinear Optical Loop Mirror (NOLM) with a 70:30 loop power splitting ratio is inserted in the ring cavity to provide the intensity dependent loss for the lasing wavelengths. An optical circulator is used to couple light out of the cavity. Oscillating wavelengths are filtered from the amplified spontaneous emission generated in the EDF by a series of FBG's with 20 % reflectivities at selected wavelengths of 1540nm, 1547nm and 1555nm. The FBG's also serve as the output coupler of the laser in which the feedback power is 20% of the cavity power and the output is 80% of the cavity power. To reduce unwanted reflections, an optical isolator is inserted in the fiber ring cavity of the laser. The output of the laser was interrogated by an Optical Spectrum Analyzer (OSA) with the resolution set to 0.05nm. The experiment was run at room temperature and the length of the Loop Mirror was varied from zero (no mirror) to 3000 m. A loop mirror with lengths 500m, 1250m, 1700m, 2500m and 3000m was used.

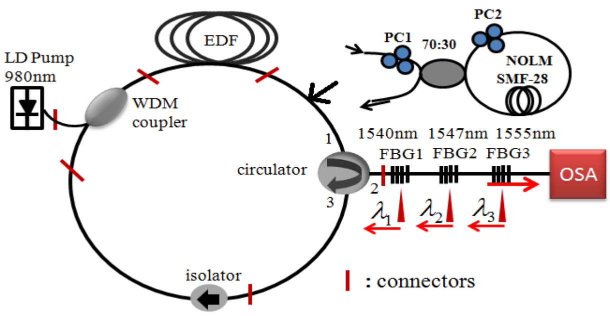

Figure 1: Schematic diagram of the experimental setup of the proposed three wavelength laser and the NOLM; PC: Polarization controller.

The room temperature operation mechanism for the multi-wavelength Erbium doped fiber laser assisted by a NOLM can be described from the transmission characteristics of the NOLM [13][14]. The NOLM transmissivity, T is given by:

$$T = 1 - 2\alpha(1-\alpha)\{1 + \cos[\theta + (1-2\alpha)\phi]\}, \qquad (1)$$

where α is the splitting ratio of the coupler used in the NOLM, θ is the phase shift induced by polarization controllers PC1 and PC2 (polarization controller 1 and 2, respectively) in figure 1 and ϕ is the nonlinear phase shift. The non-linear phase shift is given by:

$$\phi = \frac{2\pi n_2 P_{in} L}{\lambda A_{eff}}\ , \qquad (2)$$

where n_2 is the nonlinear refractive index coefficient, L is the loop length, λ is the operating wavelength, A_{eff} is the effective fiber core area and P_{in} is the Loop input power.

From equation 1, it can be seen that the transmission of the loop is a periodic function of the loop input power and can be controlled by adjusting the phase shift induced by the polarization controllers and the loop length. If the transmission loop increases with the input power, the NOLM functions as a saturable absorber, used in mode locking for pulse generation [15]. In this project the loop mirror is biased so that the transmission loop decreases with intensity; a condition leading to intensity dependent loss and therefore gain equalization for multiwavelength stability in the laser cavity. The length of the loop allows for the proper tuning of the intensity dependent loss experienced by each oscillation wavelength in the cavity for a given amount of cavity losses, and it was determined that there is an optimum loop length for this configuration.

III. RESULTS AND DISCUSSION

In a series of experiments the configuration in figure 1 was used with various Loop Mirror lengths. With no Loop Mirror in the laser cavity, the output of the laser was monitored over an approximately two hours period using an OSA and the laser spectrum in 3D view as shown on figure 2. As can be seen in figure 2, there is only one wavelength at 1540 nm oscillating in the laser cavity suggesting a huge instability and strong cross-gain saturation.

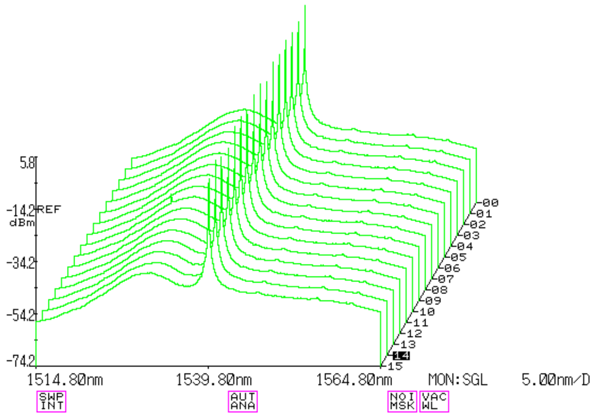

Figure 2: Spectrum of the laser without NOLM

The NOLM was introduced and the length of the loop was varied from 500 m to 3000m. The laser output was monitored over an approximately two hour period for each Loop Mirror length. When a length of 500m was used, after careful adjustment of the polarization controllers, there was no change in the lasing wavelength and the optical power fluctuations remained between -5dBm and 5dBm, as shown in figure 3. This suggests the persistence of the gain depletion by a dominant wavelength at 1540nm.

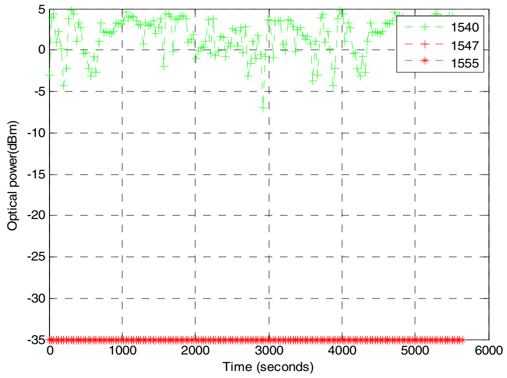

Figure 3: Wavelength and laser power stability of Laser with 500m of NOLM length.

For convenience, we have shown on figure 4, the change in the lasing wavelength stability and power fluctuations improvement with the increase in the NOLM length. It was observed that when the loop length was 1250m, a change in the number of lasing wavelengths was introduced, even though it was only the addition of one more wavelength, suggesting the weakening of the gain depletion by a dominant wavelength, as shown on figure 4.

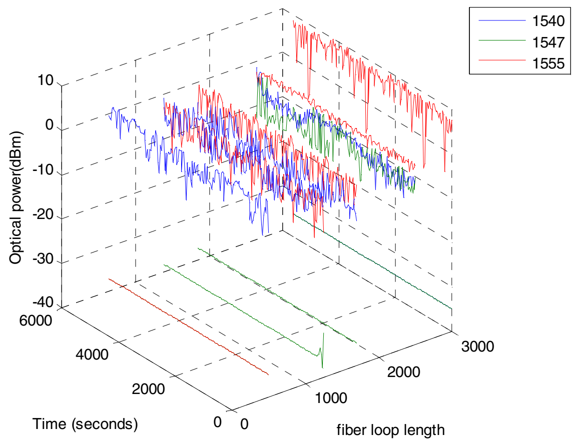

Figure 4: Laser power stability and lasing wavelength as a function of NOLM length.

From figure 4, it can be seen that the increase in the length of the NOLM increases the number of wavelengths oscillating in the cavity. However, it was also obseverved that there is a length above which a further increase in the loop length affects both the stability and the lasing wavelength of the laser. In our experiments, the length above which the satability start to decrease is 2500m, as seen in figure 4. This suggests an optimal length of 2500m is apropriate for both the maximum laser power stability and the lasing wavelength. In figure 5, a spectrum of a three wavelength fiber laser with a NOLM length of 2500m is shown. The laser has emission at 1540nm, 1547nm and 1555nm.

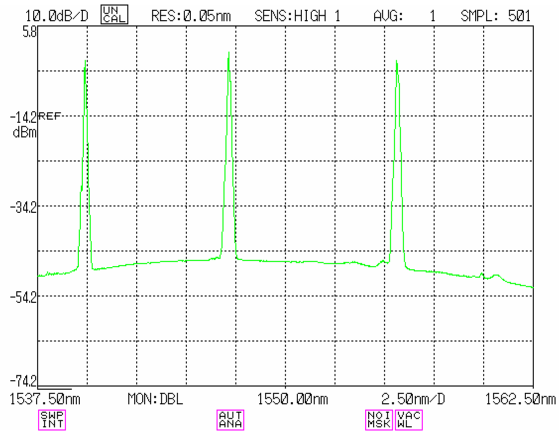

Figure 5: Spectrum of the laser with 2.5km of NOLM length in the laser cavity

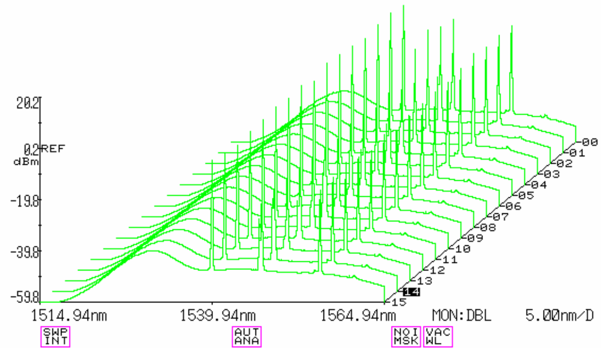

Figure 6: Emission spectrum of a three wavelengths laser with 2.5km Of NOLM length.

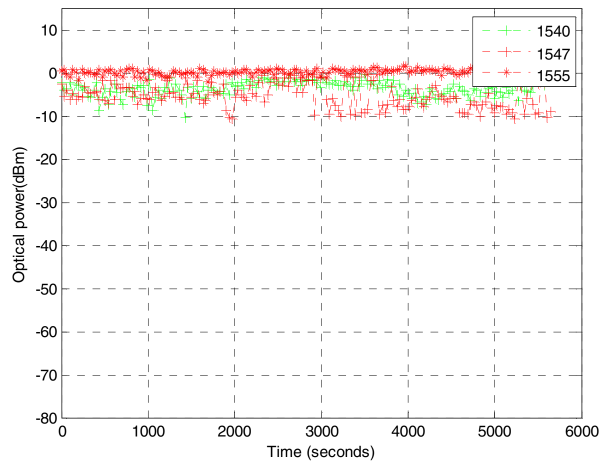

Figure 7: Laser power and wavelength stability of a three wavelength laser with 2.5km of NOLM length

After a two hour monitoring, the power stability of the laser was observed as can be seen on figure 6, the 3D plot of the laser spectrum. The power fluctuation have been observed to be minimun at this laser loop length and is shown on figure 7. This results show that a careful selectrion of the NOLM length indeed suppresses the wavelength competion in the laser cavity, leading to multiwavelength operation. Using multiples of series fiber bragg gratings can determine the number of lasing wavelength expected to oscillate in the laser. Therefore a reliable laser source for WDM systems can be achieved using our configuration.

IV. CONCLUSION

A stable three wavelength Erbium doped fiber laser with the aid of a NOLM was proposed and successfully demonstrated. This laser source configuration has proven that if the Loop Mirror length was carefully chosen, the wavelength competition in multiwavelength Erbium doped fiber lasers can be suppressed. The ITU-T standard can easily be complied with by designing the FBG's that correspond to this wavelength spectrum.

V. ACKNOWLEDGMENT

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